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A review on global renewable electricity scenario

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A B S T R A C T

Global exploitation of renewable energy technologies is increasing rapidly due to the concern in global warming and dwindling supplies of fossil fuels. Most of the countries in the world are blessed with two or more renewable energy sources (RES) and hence have formulated policies to boost the utilization of RES for their electricity production. An assessment of renewable electricity scenario is essential for research and development related works in the field of renewable energy technologies in order to further develop the renewable energy industry. Recent developments in installation capacities, costs and reductions in electricity costs of major RES based electricity generation methods are discussed in this paper. It also includes the past growth and future expectations of renewable electricity production. The analysis shows that if the current developments in renewable industry continue, then a major share of global electricity production in the future could be supplied by renewable energy technologies. The analysis further shows that a significant amount of fuel cost and pollutants emission can be reduced by the increased use of RES based electrical power production technologies.

Contents

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1. Introduction

Due to the population growth and increasing industrialization, urbanization, modernization and income growth, the global electricity consumption is expected to continue to increase significantly in years to come. According to the International Energy Outlook 2013 by the US energy Information Administration (EIA), the current global primary energy demand is 546.8 Quadribillion Btu (546.8×10^{15} Btu) and is projected to reach almost 820 Quadribillion Btu by 2040 [1]. It is expected that the global consumption of electrical energy will be doubled in the next 15–20 years [2]. It is projected that China, India, Morocco and Chili, etc. will double their electrical energy consumption in the next one to two decades [1]. Fig. 1 shows the global electrical energy consumption growth from 2010 to 2040 [1]. At present fossil fuels like coal, oil and natural gas contribute approximately 80% of global primary energy needs [3]. Reserves of these fuels are decreasing rapidly and projected depletion times for coal, natural gas and oil reserves are estimated as 103, 33 and 31 years, respectively [4]. Fossil fuel based power plants account for about 66% of world electricity production, more than 40% of which comes from coal-fired power stations [5,6]. Most of the coal-fired power stations were built two decades ago and emit about 80–85% of all pollutants generated by the power utilities. Pollutants' emission rate from some older power plants is 70–100 times greater than that from the newer plants [6]. The emissions from such plants cause global warming, acid rain, urban smog and hence are resulting in severe damage to the environment.

A rapid rise in global temperature has occurred in the 21st century due to the increase in the concentration of greenhouse gases (GHG) in the atmosphere. In 2011, global CO_2 emission reached more than 31.6 gigatonnes with an increase of 3.2% on 2010 levels and coal-fired power plants accounted for about 43% of this emission [7]. Approximately 960 kg/MWh of CO_2, 6 kg/MWh of SO_2 and 2.6 kg/MWh of NO_x are the quantities of the main pollutants emitted during the generation of electricity from coal fired power plants [8]. The effect of SO_2 and NO_x pollutants on global warming is less compared to CO_2 pollutant due to their lesser concentration in the atmosphere. CO_2 contributes the highest proportion of greenhouse effect mainly due to its higher concentration in the atmosphere. The upper safe limit of CO_2 concentration is suggested to be 350 ppm (ppm) so as not to harm the environment and CO_2 level exceeding 450 ppm is expected to cause severe damage to the environment [9]. In May 2013, the global CO_2 concentration reached almost 400 ppm and its current growth rate is more than 2 ppm/year [10]. It is projected that doubling of the CO_2 concentration from the current value will cause an increase in global temperature of 1.5–3 °C [11]. According to the Intergovernmental Panel on Climate Change report 2011, the continued emission from fossil fuels will result in an increase in the environmental temperature from 1.4 °C to 5.8 °C from 1990 to 2100 period [3]. Rapid depletion of fossil fuel reserve, awareness on carbon footprint and effect of global warming have thus forced a policy of accelerated utilization of renewable energy sources for electricity production.

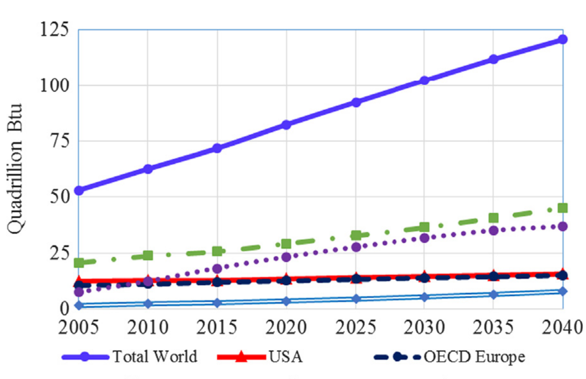

Fig. 1. Global electrical energy consumption growth over 2010–2040.

For current and future economic and social needs, the optimal use of renewable resources is essential since it minimizes the environmental impacts and produces the least amounts of secondary wastes. Natural resources like solar energy, wind power, hydropower, biomass energy and geothermal energy are the major RES for production of clean and green energy. Electricity production using RES is generally growing rapidly across the globe. Relative to the previous 4 years, the growth of renewable technologies accelerated in 2009. Renewables supplied approximately 16.6% of total world energy consumption in 2010, and the RES consumption rate increased by 22% between 2000 and 2010. Furthermore, it is estimated to increase by more than 42% during the 2010–2020 period [12]. In 2011, new global investment in renewable sector rose to 17% and there was an investment of almost 257 billion USD in this sector [13]. Moreover, the global renewable power generation in 2011 reached 4540 Tetra-Watthour (TWh) which is expected to become almost 6400 TWh within 5 years representing a growth rate of 5.8% per year [14]. About 102.6 GW of new renewable power capacities were added in 2011 which included 25 GW from hydro and 76.8 GW from non-hydro renewable resources [13]. Presently, about half of the newly added power generation capacities are by renewable power technologies [15]. According to EIA, the global renewable power capacity exceeded 1500 GW by the end of 2012. RES can cover almost 13% of global energy demand by 2020 and the share of RES in supplying global energy demand could be increased by about 14.5% by 2040 [1].

Renewable energy technologies also play the most important role in the installation of hybrid energy systems especially in remote areas where the grid extension and fuel transportation are costly due to the remoteness of the locations [16,17]. The supplementary contribution of RES to conventional power generating systems helps to meet the increasing load demands under varying natural conditions. Such hybrid systems, with a combination of conventional and renewable energy sources, reduce the total lifecycle cost and pollutant emissions while providing more reliable supply of electricity [6,18,19]. Recent literature describes updates of RES based electricity generation but most of the literatures only reported either regional or single renewable source based developments [5,20–23]. However, this paper discussed global current potential and developments in the field of major renewable energy industry.

2. Methodology

The authors have collected recent developments and projections of RES based electricity reported in the latest literatures and energy outlooks. Based on the compilation and analysis of the collected data, the continuing developments of renewable industry are highlighted and reviewed in this paper. The growth of installation capacities, reduction in capital costs as well as reduction in electricity charges of major renewable energy technologies are also briefly reported here. Furthermore, the paper points towards the future expected development in various renewable technologies.

3. Research

A careful study on global RES based electricity potential was done and the latest data of solar, wind, hydro, biomass and geothermal energies are briefed in this section. The current exploitation of renewable resources in the African continent is

comparatively less but, it has a high potential in generating a huge amount of electricity from RES in the future. The cost of RES based electricity generation as well as the projection renewable electricity potential are also discussed in this section. Comprehensive survey of developments and issues related to different renewable technologies are outlined in the following subsections.

3.1. Solar electricity

The electricity production using solar energy is growing rapidly in every part of the world. Photovoltaic (PV) and concentrated solar power (CSP) plants are utilized to produce solar electricity. Wafer-based crystalline Silicon (c-Si) and thin film amorphous Silicon (a-Si) technologies are commonly used in PV systems while parabolic trough (PT) and solar tower (ST) are the important technologies used in CSP plants. Almost 87% of global PV sales in the year 2010 were based on c-Si technology [24]. China is leading in PV cell production while European countries are leaders by the installation capacities of PV power outputs of 39 GW by the end of 2011 [21]. Almost 98% of the annual solar plants installed in the year 2012 were based on PV systems. However, CSP plants have significant potential to contribute for future energy demands. Projections indicate that CSP technologies share of the world electricity needs will become 7% and 25% by the years 2030 and 2050, respectively [2]. Most of the current installed capacities of the CSP plants are in the United States of America (USA) and Spain.

Photovoltaic is one of the fastest growing technologies in the world with a growth rate of 35–40% per year [21]. In 1983, Sharp Corporation of Japan installed the first PV plant with a capacity of 242 W which was the world largest PV plant at that time. The global cumulative installed capacity of PV plants in 2000 was 1.5 GW which has increased to almost 70 GW at the end of 2011 which represents a growth rate of 44% per year [24]. The annual PV installations reached almost 30.4 GW in the year 2011 with a 78% increase from the year 2010 [25]. In 2012, the global installed capacity of PV plants is around 31.1 GW and the cumulative installed capacities become almost 102.2 GW [25]. There are already over 80 PV plants with capacity of more than 25 MW each and most of them were commissioned during the years 2011 and 2012 [26]. Agua Caliente Solar Project in Arizona, USA, with 247 MW capacity is the world largest single PV plant at present. This plant is expected to complete in 2014 with a total capacity of 397 MW. Currently, 214 MW single solar power is produced from Charanka Solar Park in India which will be fully commissioned in the year 2014 and will have 500 MW output [26].

The commercial development of CSP plants started with solar energy generating systems (SEGS) in the USA from 1984 until 1990 when the last SEGS plant was commissioned. The first phase of SEGS plant (SEGS I) was built in 1984 with 14 MW capacity and the last phase (SEGS IX) was completed in 1990 with 80 MW capacity [2]. Now the overall capacity of SEGS plants is 384 MW which is the world largest CSP generation facility. The development in CSP restarted in 2006 with Saguaro Power Plant of 1 MW capacity in Arizona, USA. From 2007 onwards a rapid growth in the CSP plants was achieved. In 2012, the global installed capacity of CSP plants increased more than 60% and reached almost 2.55 GW [27]. Almost 94% of the installed CSP plants are based on parabolic through systems [24,28]. Annual and cumulative installed capacities of global solar plants from 2005 to 2012 are shown in Fig. 2

Europe has dominated in the PV installations since many years. In 2012, it has installed almost 17 GW grid connected PV plants while the installed capacity for the rest of the world was only about 13.9 GW. The cumulative installed capacity of Europe in 2012 reached more than 70 GW. Germany and Italy contributed almost 64% of this installed capacity [25]. The rest of the world also has a good potential for PV installation growth. European share of global PV installation in 2011 was 74% and this share was reduced to 55% in 2012. Besides Europe, the fastest PV growth is expected to continue in China and India, followed by Southeast Asia, Latin America, Middle-East and North African countries. Indian's new installed PV plant capacity in 2012 was 980 MW which is more than three times its installed capacity in 2011 [25]. Table 1 lists countries in the top 10 range in the installations of grid connected PV plants during the years 2011 and 2012 [25]. On the other hand Spain dominates in the installation of

Table 1
Top 10 grid connected PV installed countries in 2011 and 2012.

Countries	Installed capacity (GW)	
	2011	2012
Germany	7.484	7.604
China	2.200	5.000
Italy	9.284	3.438
USA	1.855	3.346
Japan	1.296	2.000
France	1.671	1.079
Australia	0.774	1.000
India	0.300	0.980
Total Europe	22.40	17.00
Total Non-Europe	7.700	13.90

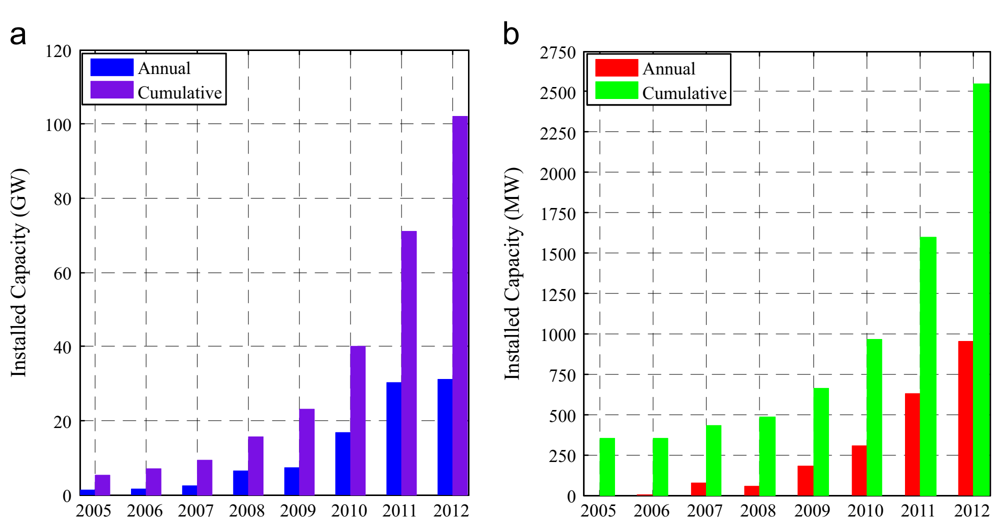

Fig. 2. Global annual and cumulative installed capacities of solar plants (2005–2012). (a) PV plants and (b) CSP plants.

CSP plants. Spain and USA contained almost 90% of global CSP installed capacity by the end of 2010. In the beginning of 2012, the installed CSP capacity in Spain reached almost 1331 MW while that of USA was 518 MW. Algeria, Australia, France, Italy and Morocco have built about 75 MW of CSP plants by the end of 2011. China, India, Iran, Italy, United Arab Emirates and South Africa, etc. are developing large scale CSP based projects in the coming years [15].

3.2. Wind power

Wind power is the largest developed and commercially utilized RES among the non-hydro renewable resource. Wind power industry achieved an average annual growth of 28% during the 2001–2011 period [20] and its average installed capacity has doubled every 3 years. With the addition of 41 GW capacity in 2011, the total wind power installed capacity at the end of 2011 was 20% higher than at the end of 2010. More than 80 countries now use wind power commercially and global installed capacity of wind power was more than 238 GW at the end of 2011 [20,24,29]. According to the European Wind Energy Association (EWEA) statistics, almost 94 GW installed wind capacity is in Europe, whereas, Asia has 82 GW and North America had 53 GW of wind power installed at the end of 2011 [30]. According to the Federal Network Council (FNC) of Germany, in August 2012 the new globally added installed wind power capacity was 28.859 GW with 28.771 GW from onshore and 0.188 GW from offshore wind farms [31]. Global cumulative installed capacity of wind power reached 283 GW with almost 18.7% cumulative growth rate by the end of 2012 [27]. Annual and cumulative global wind power capacities are shown in Fig. 3.

In 2011, about 51%, 25% and 20% of global wind power capacities were added by Asia, Europe and North America, respectively. The Asian wind power sector will overtake in terms of cumulative wind capacity by 2013 [24,29,30]. Only China installed 44.3 GW and 62.3 GW of wind power in 2010 and 2011, respectively [20]. Almost 43% of newly added global wind power capacity in the year 2011 was from China and the domination of China in new additions will continue. China, United States, Germany, Spain and India contributed more than 74% of world wind power installed capacity at the end of 2012. The installed capacity and share of global wind capacity of these counties in 2011 are given in Table 2.

Europe is dominating in the installed capacity of global offshore wind farms. Denmark installed its first offshore wind farm in 1991. There were almost 53 offshore wind farms in Europe at the end of 2011 with an operating capacity of 3813 MW [32]. Walney wind farm in the United Kingdom with a capacity of 367 MW is the largest offshore wind farm in the world. EWEA has the target to install offshore wind farms of 40 GW by 2020 and 150 GW by 2030 [32,33]. China also has two offshore wind farms with a total capacity of 232 MW and plans to install 5 GW offshore wind farms by 2015 and 30 GW by the year 2020 [24].

3.3. Hydropower

Hydropower is the world largest clean and renewable energy source with almost negligible levels of greenhouse gas emissions. About 16% of the world electricity is from hydroelectricity which represents more than 85% of the world's renewable electricity produced [24]. More than 150 countries now produce hydroelectricity. Total global hydropower potential is approximately 970 GW with the addition of 25 GW of new capacity in the year 2011 [13]. World hydroelectricity energy production was about 3500 TWh in the end of 2011: China, Canada and United States together produce almost half of the world's hydroelectricity. About seven countries have hydroelectricity production of more than 100 TWh and six countries produce more than 50% of their total electricity needs from hydropower as shown in Fig. 4 [24,34].

In China hydropower accounts for almost 15% of the country's total electricity generation and 20% of global hydroelectricity [34]. China added about 49% of global new hydro installed capacity in 2011 alone when its total hydro capacity reached 212 GW. Approximately, 75% of new hydro installations in 2011 was contributed by five countries as shown in Fig. 5. Europe dominates in pumped storage hydropower plants. Global installed pumped storage capacity is around 130–140 GW and Europe accounts approximately 35% of global pumped storage capacity. Japan, United States and China have around 25.5 GW, 22 GW and18.4 GW pumped storage installed capacity, respectively [13].

Table 2
Installed capacity and share of global wind power in 2011 [20].

Country	Wind power capacity (GW)	% Share of global wind power
China	62.33	26.3
United States	46.919	19.4
Germany	29.060	12.2
Spain	21.674	9.1
India	16.084	6.8

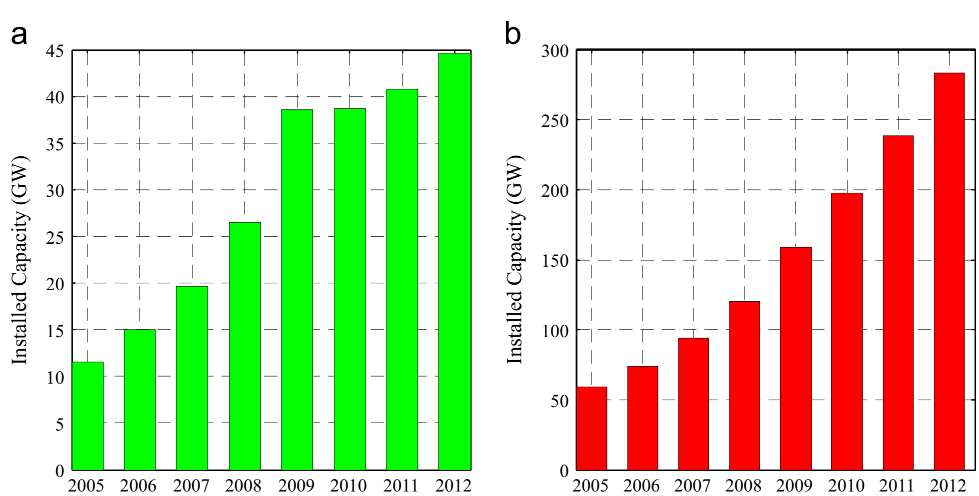

Fig. 3. Global wind power installed capacities (2005–2012). (a) Annual and (b) cumulative.

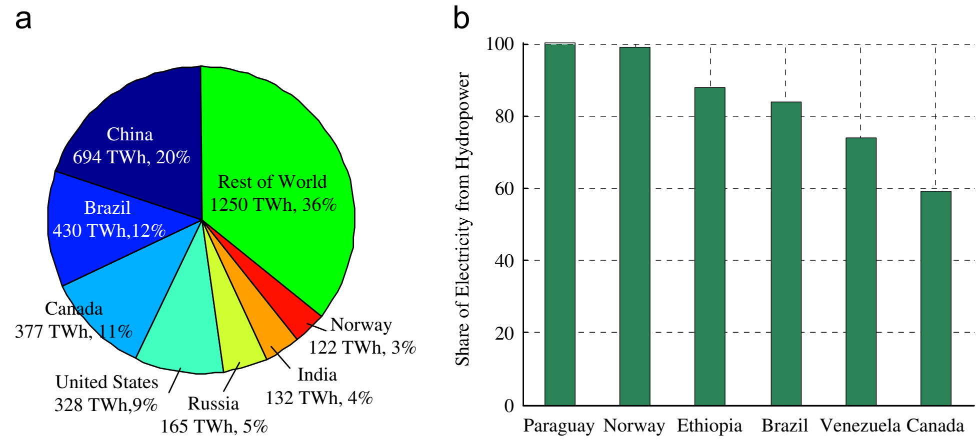

Fig. 4. Hydroelectric generation status in 2011. (a) Hydroelectricity (TWh) and (b) countries with $>50\%$ of electricity share from hydro.

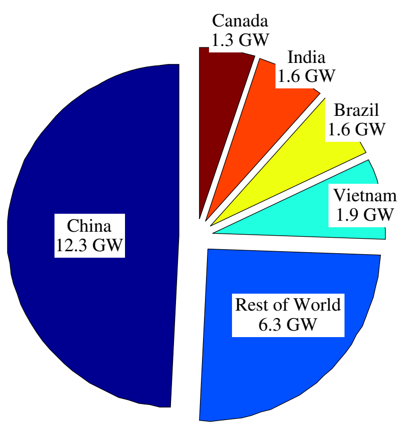

Fig. 5. Top five countries with hydropower capacity additions in 2011.

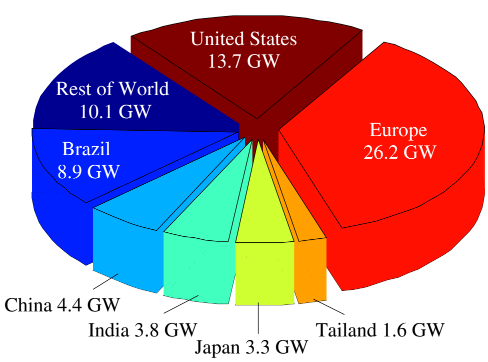

Fig. 6. Global biomass power capacity in 2011.

3.4. Biomass energy

Biomass resources are organic renewable energy sources which are widely distributed and have good potential to generate electricity in rural areas. Solid biomass, biogas and biodegradable municipal solid waste (MSW) are the main biomass resources. Electricity is generated from these resources by direct firing or co-firing in either electricity only or combined heat and power (CHP) plants. About 86% of the current estimated biomass demand of 53 exajoule (EJ) is used for heating and cooling purposes while 10% of this amount is accounted for global primary energy supply. Biomass energy is the fourth largest source for world energy demand [13]. Recently the world's largest biomass plant has been commissioned on November 2012 with a capacity of 200 MW in Poland. Approximately, 410 MW biomass power had been installed in the United States by 2012. The global operating biomass plant capacity was around 72 GW at the end of 2011 with 5.9 GW being added in the year 2011 alone [13]. About 85% of global biomass plants are located in Europe, North and South American countries. Over 88% of biomass power is generated from the solid biomass fuels. About 82% of total European biomass power and more than 73% of total North American biomass power is also produced from solid biomass fuels [24]. The global biomass power capacity at the end of 2011 is shown in Fig. 6.

3.5. Geothermal power

Thermal energy available from the Earth's interior is used for geothermal power production. A major portion of the Earth's geothermal resources is unexplored and only a very small portion is identified. Identified geothermal resources are technically capable to produce around 240 GW of electrical power [35]. Flash type plants are used to produce electricity from high temperature based geothermal resources while binary cycle plants are used to generate electricity from medium temperature resources. At the end of 2011, the global geothermal power capacity was 11.2 GW with a capacity growth rate of 1% in the year 2011[13]. According to Geothermal Energy Association (GEA), as of August 2013, the global operating geothermal power capacities is about 11.765 GW. Moreover, several hundred MW capacities are under final stages of construction. The global geothermal power capacity is expected to reach 12 GW by the end of 2013. At present, there are over 674 developing geothermal projects across the world and about 11.766 GW geothermal power capacity is in the early stage of developments (i.e. initial explorations and construction are underway) or under construction (physical work to build actual plant has begun) in 70 countries [36]. Geothermal power plants are operating in at least 24 countries and about nine countries are having geothermal power projects under construction with a capacity of more than 40 MW. The United States, Philippines, Indonesia, Mexico, Italy, New Zealand, Iceland and Japan are the top eight countries with the highest installed geothermal power capacities. Geothermal power plant capacities of these top eight countries and plant capacities under construction are shown in Fig. 7. Countries like Chile, France, Rwanda, Tanzania and Uganda will have their first operational geothermal power plants within the next few years [13,36].

3.6. Renewable energy potential in Africa

Even though the potential of renewable resources is abundant in the African continent, the RES based electricity generation is utilized to a very less extent compared to the other RES rich

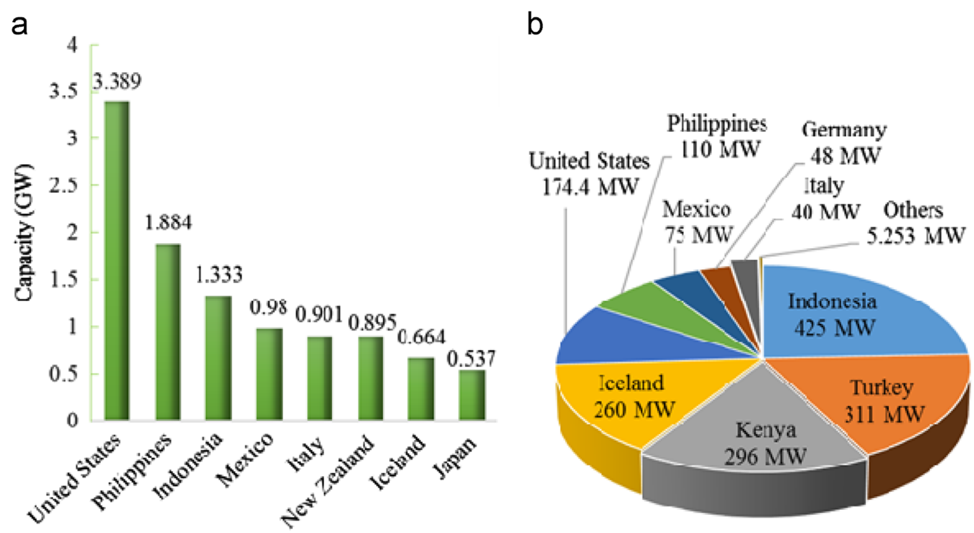

Fig. 7. Global geothermal power status [35]. (a) Plant capacities for top eight countries and (b) plant capacities under construction.

Table 3
Percentage share of energy resources utilized for the electricity in Africa [37].

Fuel	SA	SSA	NA
Coal	94	5	4
Gas	–	16	68
Oil	–	18	21
Hydro	1	60	6
Others	5	1	1

regions of the globe. This is due to the unreliable or undeveloped infrastructure and deficiency of financial resources. Africa consumes only one-fourth of the world average energy per capita by utilizing the mix of fossil, hydro and biomass based resources. More than 90% of electricity generation in South Africa (SA) is from coal fired power plants while North African (NA) countries generate their major share of electricity from gas based plants. However, Sub-Saharan African (SSA) countries depend on hydropower to generate almost 60% of their electricity needs [37]. Shares of fuel resources utilized for generation of electricity in Africa are given in Table 3. Solar, wind, hydro, geothermal and biomass are the main renewable resources available in the African continent. Due to the diverse nature of the continent, the availabilities of such resources vary in different African countries. South Africa is one of the best solar resource parts in the globe and has approximately 194,000 km^2 of area with high solar radiation. Projected electricity demand (80 GW) of SA in 2025 could be met by the utilization of about 1.25% of this area through CSP plants [38]. About 20 countries of SSA have RES potential to generate electrical energy which is more than 10 times their current energy consumption. In Namibia, about 100 times the current annual energy consumption can be met by the utilization of RES, while in the Central African Republic and Mauritania, this capacity is about 91 and 86 times, respectively [39].

At present, African countries are taking some steps to meet part of their electricity demand by the utilization of one or more renewable resources. At least 21 countries are concentrating on solar and wind based electricity generation, whereas about 14 countries have focused on biomass based generation. Geothermal based power generation is being explored by about seven counties [37]. North African countries have targeted to increase their RES based electricity to meet about 50% of their load demand by 2020 [37,40]. Algeria aims to cover 6% of power generation with RES by 2015. By the end of 2020, Egypt and Libya have targeted to meet about 14% and 6%, respectively, of their power demand with RES based generation [40]. Morocco has set a target of 20% of electricity generation using renewable resources by 2020 [37]. The 18th submit of the African Union planned to implement nine hydropower projects in the SSA regions by 2020 with an overall capacity of 50 GW [37]. In 2009, about 20% of Mauritius total electricity consumption was supplied by bagasse based co-generation and it is projected that this share can reach about 35% by 2025 [37]. The White paper on renewable energy published by the SA government in 2003 has targeted to meet 10,000 GWh of energy consumption through the use of renewable energy by the end of 2013. As part of this goal, its government has started a rebate scheme since 2009 to reduce the cost of solar and heat pumps. Replacing electric water heater with solar water heater can reduce about 30–50% electricity consumption of an average household in SA [37]. Improved cooking stove in Mali, Cows to Kilowatts project in Nigeria, Five Revenue Streams of Mumias Sugar Company in Kenya, etc. are some of the examples of recent initiatives for clean RES based electricity generations in Africa [37].

3.7. Cost for renewable power

The installation cost and cost of electricity of renewable energy plants vary with technology, country and the renewable resource employed. The electricity cost also depends on the maintenance and operating cost and efficiency/performance of the technology used. The approximate range of renewable power plants costs is given in Table 4. Due to the rapid growth of the market, the PV module costs decreased at a rate of 22% per year recently. From 2008 to 2011 the PV electricity system's costs have decreased by 40% [15,21]. Crystalline PV module's price from Chinese manufacturers in December 2012 dropped to 0.75 USD/W, whereas at the end of 2011, the average PV module price was almost 1 USD/W. However, PV modules from western manufacturers were more expensive at almost 1.1 USD/W at the end of 2012 [15]. In the second quarter of 2012, the average installation cost and cost of electricity production by PV plants were in the range of 2.2–4.8 USD/W and 15–44 cents/kWh, respectively [13,15]. In 2009, the average installation cost of CSP plants was in the range of 2.5–4 USD/W [28]. The capital cost of parabolic trough CSP plants at a capacity factor of 20–25% and without storage is almost 4.5 USD/W and this cost approximately doubles when the storage facilities are added to the CSP plants [13]. Due to the declining trend in the cost of the PV modules, the cost of CSP plants is expected to be more competitive in the future. According to the

Table 4
Cost of renewable power plants [13,24].

Types	Characteristics	Capital costs (USD/kW)	Energy costs (USD/kWh)
PV rooftop	*Capacity:* 3–5 kW (residential) 100 kW (commercial) 500 kW (industrial) *Efficiency:*12–20%	2480–3270	0.22–0.44
PV ground-mounted	*Capacity:* 2.5–100 MW *Efficiency:*15–27%	1830–2350	0.20–0.37
CSP parabolic trough (with 6 h storage)	*Capacity:* 50–500 MW *Capacity factor:* 40–50%	7100–9000	0.188-0.29
CSP solar tower (with 6–18 h storage)	*Capacity:* 50–300 MW *Capacity factor:* 40–80%	6300–10,500	0.17–0.29
Wind onshore	*Capacity:* 1.5–3.5 MW *Rotor diameter:* 70–125 m *Capacity factor:* 20–40%	1410–2475	0.052–0.165
Wind offshore	*Capacity:* 1.5–7.5 MW *Rotor diameter:* 60–110 m *Capacity factor:* 35–45%	3760–5870	0.114–0.224
Hydro grid based	*Capacity:* 1–18,000 MW *Capacity factor:* 30–60%	2000–4000	0.05–0.10
Hydro off-grid/rural	*Capacity:* 0.1–1000 kW	1175–3500	0.05–0.40
Biomass CHP	*Capacity:* 8.8 MW *Capacity factor:* 85%	4000	0.07–0.29
Biomass stocker/fluidized bed boilers/steam turbine	*Capacity:* 25–100 MW *Capacity factor:* 70–80% *Efficiency:*27%	3030–4660	0.08–0.176
Geothermal condensing flash	*Capacity:* 1–100 MW *Capacity factor:* 60–90%	2100–4200	0.057–0.084
Geothermal binary cycle	*Capacity:* 1–100 MW *Capacity factor:* 60–90%	2470–6100	0.062–0.107

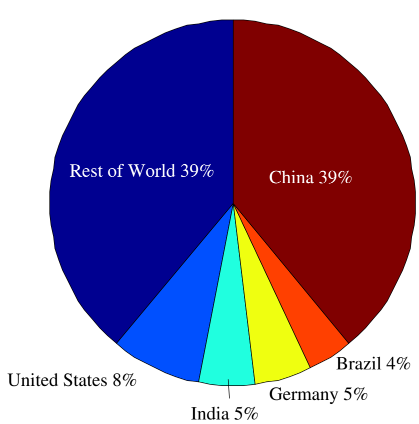

Fig. 8. Projected share of global renewable capacity additions in 2011–2017.

IRENA publication in June 2012, the cost of both installation and operation of CSP plants are expected to decrease.

The installation cost for onshore wind farms in 2010 was typically in the range of 1850–2200 USD/kW in most of the markets, while it was in the range of 1300–1400 USD/kW in China and Denmark [24]. However, offshore wind farms are more expensive and their installation costs are in the range of 4000–5000 USD/kW. About 64–84% of the total installation costs account for the cost of wind turbines in the onshore farms whereas 30–50% of the wind project costs account for the turbine costs in the offshore wind farms [15]. During 2001 and 2002, the wind turbines costs were at the lowest levels whereas these costs reached to peak levels during 2008–2010. In 2011 and 2012, the installation costs of wind farms decreased due to the decrease in the cost of wind turbines. The turbines cost in 2012 had declined by almost 11–29% from the 2008 peak levels, while it still remains more than the 2002 levels [24,41].

Hydropower at good sites provides the cheapest electricity generation cost. The capital cost of large hydropower plant with a capacity factor of 30–60% is less than 2000 USD/kW if the plant size is in the range of 1–300 MW, while it becomes 2000–4000 USD/kW for plants with a size of more than 300 MW [13]. The upgrading of the existing hydropower plants can be done easily with costs that are as low as 500 USD/kW [15].

The total installed costs of the biomass plants varied between 1.88 and 6.8 USD/W in 2010. The capital cost is very low when biomass is co-fired with fossil fuels. In such a case, it is in the range of 140 USD/kW and 850 USD/kW without including the original investment in the plant. About 9–20% of the cost of electricity depends upon the operation and maintenance cost and it varies from 0.04 to 0.29 USD/kWh. Among the biomass plants, the cost of electricity-only plant configuration is much less than the cost of CHP plants [24].

The capital cost of geothermal plants includes the costs of exploration and resource assessment, costs for drilling and re-injecting wells with a success rate of 60–90% and the cost associated with power plants and grid connections. At present, the installation cost of geothermal plants are 60–70% higher than their levels in 2000 [15]. Binary cycle plants are more expensive than the condensing flash type geothermal plants. The running costs of geothermal power plants are very low and are in the range of 0.057–0.084 USD/kWh for condensing flash type and 0.062–0.107 USD/kWh for binary cycle geothermal plants [13].

3.8. Projections of renewable potential

The growth of renewable technologies accelerated in 2009 relative to the previous 4 years. In 2011, about one-third of newly built power generation capacities were met by renewable power sources. The expected growth of renewable electricity generation within the next 5 years is 1840 TWh which is almost 60% higher than the growth reported during the 2005–2011 period. According to the International Energy Agency (IEA), the addition of global renewable power capacity in the 2011–2017 period is projected to reach 710 GW and China is projected to account almost 40% of this value [14]. According to the US Energy Information Administration (EIA) projections, the fossil fuel's share of the electricity market should decline to 66% by 2035 from the share of 71.4% in 2008 while that of RES share will increase from 9.1% in 2008 to 17% by 2035 [42]. According to the world energy council projections, by 2025 about 60% of the world electricity supplies would be provided by RES [3]. Fig. 8 shows the projected share of key countries to global renewable capacity additions over the next 5 years.

Within the next 5 years, almost 70% of the global renewable electricity share is expected to be from hydroelectricity. Over 200 countries are expected to achieve more than 100 MW of non-hydro renewable capacities by 2017. Among these countries, about 83 should have more than 100 MW capacities from wind power, 60 from solar, 45 from bioenergy and 14 countries from geothermal power plants [14]. More than 90% of newly added wind capacities for the next 5 years are expected from onshore wind farms with China contributing over 40% of such additions. The newly added capacities for PV plants within these 5 years should reach about 130 GW out of 139 GW of new solar plant capacities [14]. Geothermal power capacity is expected to reach 14 GW in 2017 with a 4.2% of generation growth per year [14]. According to EPIA projections the PV will contribute almost 345 GW by 2020 and 1081 GW by 2030 [21]. Some projections suggest that approximately 25% of the total projected electricity needs for the world by 2050 can be contributed by CSP technology [2]. According to the IEA projection in 2010, the world hydropower production could grow by 75–85% over the 2007–2050 period [24]. The total capacity of biomass power plants expected to be completed in 2013 is about 10 GW and biomass and waste based power generation would grow from 62 GW in 2010 to 270 GW in 2030 [24]. The expected global renewable potential at the end of the next 4 years is given in Table 5.

Table 5
Global renewable potential in 2017 [14].

Plants	Global electricity generation (TWh)	Share to renewable electricity (%)	Cumulative capacity (GW)
Solar	310	4.9	241
Wind	1065	16.5	486
Hydro	4378	69–70	1070–1300
Bioenergy	532	8.3	119
Geothermal	91	1.4	14

4. Discussion

The latest energy outlook reports and literatures indicate that most of the counties are aware of the benefits of the utilization of renewable energies. A significant share of global electricity demand can be produced using RES in the near future if these countries accelerate their research for the development of renewable technologies and install the most suited and advanced RES based power plants. China is blessed with plenty of renewable resources. It has the largest wind resources in the world and has a significant position in the globe for the utilization of solar, hydro and biomass resources. About 30% of the world's PV panels are produced by China. Geothermal resources are also widely distributed throughout this country. Moreover electrification of rural areas in China using renewable resources is easy and economical due to the significant potential of RES. However, in spite of all these factors more than 70% of China's electricity is produced by coal fired power plants which makes China the largest contributor of global CO_2 emission. In 2011, the country's CO_2 emission increased by 720 million tonnes and 16 of the world's 20 most polluted cities are in China [7,43]. Hence, China has to boost the utilization of renewable resources for clean and sustainable power supply and future wellbeing. Government policies and initiatives will lead to the installation of new renewable power production capacity in China. Canada, Brazil, USA, Russia and India also have significant potential for hydropower which can help these countries to generate clean electricity in order to meet a significant share of their power demands. Even though the highest potential of solar irradiation is available in South Africa and Middle Eastern countries, more than 90% of electric power demand of these countries is met by fossil-fuel based power generation since fossil-fuels are cheap and plentiful in these countries. These countries have already started to take some steps to increase the utilization of solar power in order to save fossil fuels for future generations and to reduce the pollutants emissions. The substitution of fossil-fuel with renewable biomass based on efficient, clean and convenient technologies will reduce the CO_2 emissions from the energy systems. European countries, USA, Brazil, India and Russia have good potential of biomass for generating clean electricity [7]. Offshore wind resources have better potential than onshore generations since offshore wind has high speed and less

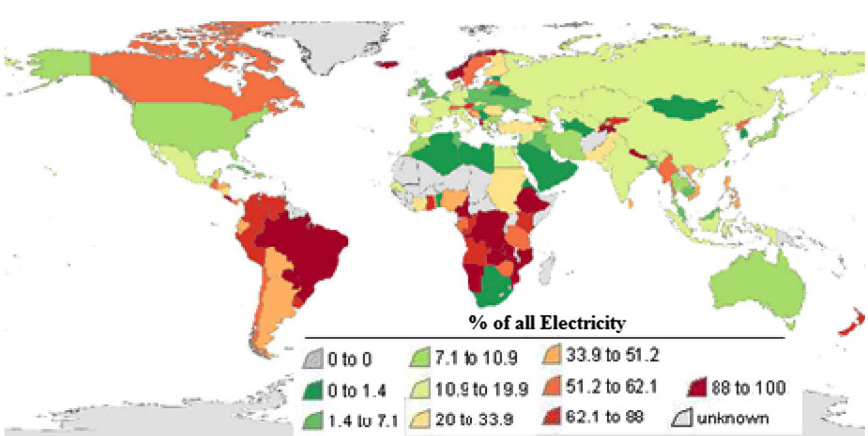

Fig. 9. Map of global RES based electricity share [45].

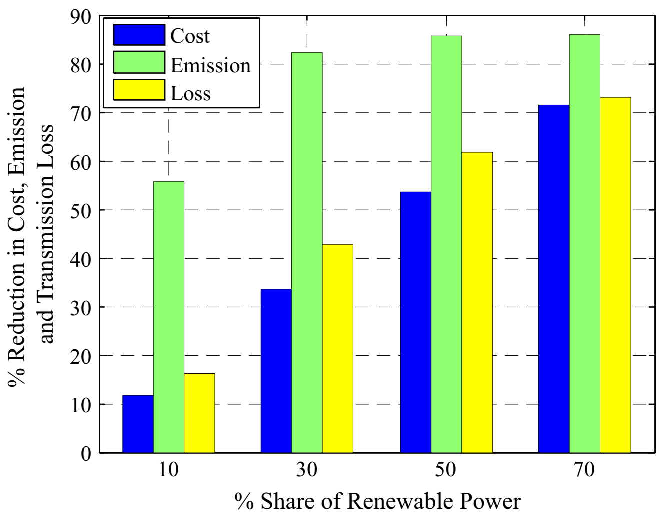

Fig. 10. Reduction in fuel costs, pollutant emissions and transmission losses for various levels of renewable penetrations.

intermittence. Most of the offshore wind projects exist on seabed or in waters no deeper than 30 m. Hence offshore wind plants have good potential to contribute power demand since nearly half of the world's population live near the coastal areas. Northern Europe, China and USA have good possibilities to develop offshore wind projects. China and USA have already started offshore wind projects and have plans to reach 30 GW and 10 GW of such plants, respectively by 2020 [44]. Share of global RES based electricity of the total electricity generation of various region is shown in Fig. 9.

The growth of renewable energy in OECD countries is expected to come from wind and biomass while in the Middle-East, this growth is expected to be based on solar. However, hydropower is expected to be the fastest growing renewable energy in developing countries. Moreover, the use of efficient operating policies and power system managements can ensure optimal results in economic and environmental friendly utilization of RES. High potential renewable resources facilitate distributed generation and hybrid power systems. Distributed generation helps the utilities to generate electricity from RES and to sell the excess electricity to the grid. Hybrid power systems which include both conventional and renewable power plants have very significant roles in power system scheduling such as unit commitments, power dispatch, peak power shaving and demand response, etc. Another benefit of high potential RES is the reduction of transmission losses by using renewable power from the locally installed renewable plants near the load centers since transmission loss is considerable for long distance power transmission. Hence, RES are expected to have a very promising role in smart grid implementation [46–49].

Power dispatch with high potential RES is capable of saving a major share of fuel costs and reducing a significant amount of pollutants emission and transmission losses. Production and storage of renewable energy at times when there would be a surplus of its availability or at off-peak times and reuse of such stored energy during its unavailable periods makes power dispatch problems more effective [6,50]. We have illustrated an example of power dispatch at a hybrid system using IEEE-30 test bus data of six generators [6] with various levels of renewable penetration. If the fuel cost, amount of pollutants emission and transmission loss from the hybrid system while dispatching 5 pu of demand without using RES are 1137.9 USD/h, 1.5074 t/h and 0.03 pu/h, respectively, then the percentage reduction in fuel costs, pollutants emissions and transmission losses when 10% of demand is contributed by renewable energies are approximately 12%, 56% and 16%, respectively. It is estimated that if 50% of the power to be dispatched is contributed by the RES then more than 50% of fuel costs, pollutants emissions and transmission losses can be reduced as shown in Fig. 10.

5. Conclusions

Recent developments including costs of generation and projected growths of major renewable energy technologies have been discussed in this paper. It is concluded that the growth of RES based electricity generation is required globally in order to meet the high needs of electricity required in the future without affecting the environment. It is suggested that every country should constitute a renewable energy promotion council (REPC) in order to increase the utilization of RES by promoting research and developments and by providing support and subsidies to install RES based power plants. It is also recommended to constitute a global REPC with the objectives of monitoring and promoting renewable energy developments in each country and supporting undeveloped countries to boost their RES based development by providing significant funds by agencies such as the World Bank and other donors and financiers.

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Appendix A

Capacity factor

It is the ratio of the actual energy produced by a power plant in a given time period, to the energy that would be produced from continuous operation at full rated power (i.e. hypothetical maximum possible).

Capital costs

Capital costs (usually expressed in \$/kW) of a power plant are the fixed costs to construct the plant and major maintenance work that needs to be carried out during the life-time of the plant beyond typical operating expenses. These costs include the following,

1. Land and building cost.
2. Civil works and structural costs.
3. Mechanical instrument supply and installation costs.
4. Electrical, Instrumentation and control costs.
5. Project indirect cost, etc.

Energy costs

Energy cost is the cost (usually expressed in \$/kWh) for generated electricity and depends on capital costs, operation and maintenance costs, capacity factor, etc. It varies with country, region, type of fuel and technology used for generation, etc. It is expressed as

$$EC = \frac{\sum_{y=1}^{N} \left(\frac{I_y + M_y + F_y}{(1+R)^y} \right)}{\sum_{y=1}^{N} \left(\frac{E_y}{(1+R)^y} \right)} \tag{A.1}$$

Table A1
Generator cost and emission coefficients.

Generator	Cost			Emission				
	a	b	c	α	β	γ	λ	δ
1	10	200	100	4.091	−5.554	6.490	2×10^{-4}	2.857
2	10	150	120	2.543	−6.047	5.638	5×10^{-4}	3.333
3	20	180	40	4.258	−5.094	4.586	1×10^{-6}	8
4	10	100	60	5.326	−3.55	3.380	2×10^{-3}	2
5	20	180	40	4.258	−5.094	4.586	1×10^{-6}	8
6	10	150	100	6.131	−5.555	5.151	1×10^{-5}	6.667

where, EC is the average cost of energy generation, I_y is the investment expenditure in the year t, M_y is the operation and maintenance expenditure in the year t, F_y is the fuel expenditure in the year t, E_y is the electricity generation in the year t, R is the discount rate and N is the life of the system.

Fuel cost function in \$/h

$$F_C(P_{gi}) = \sum_{i=1}^{N_g} a_i + b_i P_{gi} + c_i P_{gi}^2 \tag{A.2}$$

a_i, b_i and c_i are the cost coefficients for the ith generator, P_{gi} is the real power output of the ith generator and N_g is the number of generators.

Emissions function in ton/h

$$F_E(P_{gi}) = \sum_{i=1}^{N_g} \alpha_i + \beta_i P_{gi} + \gamma_i P_{gi}^2 + \lambda_i e^{\delta_i P_{gi}} \tag{A.3}$$

α_i, β_i, γ_i, λ_i and δ_i are the emission coefficients of the ith generator.

Transmission losses function in pu/h

$$F_L(P_{gi}) = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_{gi} B_{ij} P_{gj} + \sum_{i=1}^{N_g} B_{0i} P_{gi} + B_{00} \tag{A.4}$$

B_{ij}, B_{0i} and B_{00} are the transmission loss coefficients.

IEEE-30 test bus data

The cost and emission coefficients of the generators used in the test system are given in Table A1. Lower and upper limits of generator output powers are assumed as

$$0.05\ \text{pu} \le P_{gi} \le 1.5\ \text{pu}; \quad i = 1, 2, \ldots, 6 \tag{A.5}$$

Transmission loss coefficients

$$B = \begin{bmatrix} 0.0017 & 0.0012 & 0.0007 & -0.0001 & -0.0005 & -0.0002 \\ 0.0012 & 0.0014 & 0.0009 & 0.0001 & -0.0006 & -0.0001 \\ 0.0007 & 0.0009 & 0.0031 & 0 & -0.0010 & -0.0006 \\ -0.0001 & 0.0001 & 0 & 0.0024 & -0.0006 & -0.0008 \\ -0.0005 & -0.0006 & -0.0010 & -0.0006 & 0.0129 & -0.0002 \\ -0.0002 & -0.0001 & -0.0006 & -0.0008 & -0.0002 & 0.0150 \end{bmatrix}$$

$B_0 = 10^{-3}[0.3908 \quad 0.1297 \quad -0.7047 \quad -0.0591 \quad -0.2161 \quad 0.6635]$

$B_{00} = [0.0056]$

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